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COMPARATIVE ANALYSIS

OF THE

FINK, MURPHY, BOLLMAN & TRIANGULAR

TRUSSES,

BY C. SHALER SMITH,

CIVIL ENGINEER.

BALTIMORE:
JOHN W. WOODS, STEAM BOOK AND JOB PRINTER,
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1865.

UNIVERSITY OF

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Comparison of Four Leading Forms of Bridge Truss,

Viz. those known as the Bollman, Fink, Murphy, and the Triangular; the last called in England the "Warren Girder," (but exhibited here in an improved form) by C. SHALER SMITH, *Civil Engineer.*

THE writer of what follows under the above heading has been engaged almost exclusively for some years in the department of his profession to which it refers, and now submits to his fellow Engineers and the public the results of his inquiries into the principles of bridge trusses and their practical applications, as illustrated by the above forms.

He is aware that the four patterns above enumerated, do not by any means embrace all the modifications of which the several elements of a bridge truss are susceptible. They represent, however, the distinguishing features of the several models which are now most prominently competing for the favor of Engineers and Bridge builders.

The Howe truss, heretofore the favorite form and still so for moderate spans and with wood as a material, is rarely used when the opening exceeds 150 feet without the accompaniment of an arch to which it is in fact but an auxiliary; the lattice, long since abandoned as a wooden structure, and but little employed in iron in America although largely so in Europe; the bow string truss, of which it is believed there is as yet no example with us although claimed in Europe to be, for the weight it will carry, the lightest of all; the tubular or boiler plate girder, used upon a grand scale in England and Canada, but too costly for the United States, except for short spans and usually in the I form; the suspension bridge proper, with its back anchorage and its heavily trussed floor of which there is but the one actual erection, that at Niagara; all of those have either had their day in this country or have not yet been introduced upon our public works, in a form and manner to recommend them to our preference. The writer has therefore, without disparagement to other forms, confined himself to a comparison of the above four trusses which are at this time contending most spiritedly for the prize of professional and popular patronage. In his analysis of the elements of each truss, he has pursued the most simple and practical methods, resorting to mathematical formulæ only so far as was absolutely necessary to exhibit the relations between the several parts of the various combinations, the strains to which they are subjected, and the resistances they are capable of offering. To Engineers well versed in the higher mathematics and accustomed to employ them in the solution of all such questions, his mode may appear too little scientific; but as he is writing more for the less theoretically accomplished members of the profession, and for those practical bridge builders to whom so many of this class of constructions are committed, he prefers to proceed as he has done in this case. The books and journals abound in theories of trusses expressed in algebraic symbols unintelligible to nine-tenths of their readers, and however ingenious, and even sound, the theories reached through their complex equations may be, they are so entirely disregarded by the designers and builders of the structures to which they refer, that they are in effect only an agreeable exercise of the faculties of the learned men who propound them. It is not intended to depreciate high science or the labors of those eminent men who have discovered and developed the elementary principles upon which all correct theory and sound practice are founded, but only to justify the use of simpler processes in demonstrating them to the partially instructed class who apply them in actual construction. In truth, the conditions of the several questions which present themselves in planning a truss, are so many, and so founded upon what the Engineer who experimentally tests the bridge can alone obtain a full knowledge of by noticing the effect of passing trains at various speeds, that it is not to be wondered at, that the skillful algebraist, in framing his equations in his study from only a general idea of the movements which take place, should omit some quantity which ought properly to enter into them.

The writer is aware, that upon this subject many works, some of them of great merit have been published of a practical as well as scientific character, and he by no means expects to render a reference to them unnecessary by the present brief exposition, the object of which, as already stated, is to submit a comparison, based upon established facts, of the forms .of truss between which, in view of all the circumstances effecting the question in this country, a choice is most likely to be made.

He may expect his conclusions in favor of the models he prefers to be disputed, and so far from deprecating criticism he invites it, on the simple condition that it be temperate and fair, and free from the personalities and side issues which so often take the place of sound argument upon the true points in controversy.

He has no property in any of the patents involved in the different systems, and no other interest in the adoption of one rather than another, except in so far as his demonstration of its superior economy may cause a structure to be erected, which on a more expensive plan would not be built at all. If his effort should, upon this ground, result in increasing the replacement of temporary and unsafe by permanent and reliable constructions of moderate cost, his field of labor in this branch of his profession will be enlarged, not of course exclusively but in fair competition with others whose interests as well as his own, he will thus have been instrumental in promoting. With these prefatory remarks he will proceed with the comparisons following.

GENERAL PRINCIPLES AND DATA.

In order to prepare the several designs for comparison with each other, it will be necessary to assume first, a certain span, depth, width and weight of truss, and of quiescent load uniformly disposed over its length; secondly, to assign the position of the track and load, whether at the top or bottom of the truss, thirdly, to compute upon the established rules for composition and resolution of mechanical forces, the several tensile and compressive strains upon each part of the framing, under the uniformly distributed load in a state of rest; fourthly, to exhibit the strain to which each part is subjected by the moving load of the locomotive and its train, and the disturbing effect of such strains upon the arrangement of those parts; fifthly, to show the effect of changes of temperature upon that arrangement of parts; sixthly, to consider the means of adjusting the several parts which the principle of framing affords, and by which the truss can be restored to its proper condition after disarrangement from any cause.

The first and second of the preceding conditions being settled as necessary preliminaries to our inquiry, and, under the third and fourth heads, the several strains upon each part having been calculated simply as *lines* of tension or compression, the next step is to determine the sectional dimensions to be given them, and the material best adapted to the duty to be performed, as well as the proportion of strain to ultimate strength, or the limits of *safety* within which the actual stress upon the several parts of the respective systems of framing should be confined. These calculations having been made, the quantities of material of each kind in each form of truss will be determined, and may be compared with each other and their economical relations decided, in this particular, leaving them to be compared finally under the fifth and sixth heads of effects of temperature and adjustability of parts.

Under the first and second heads we will then assume, that the span of the truss is 200 feet, the depth 21 feet, and the width of floor from centre to centre of the trusses 18 feet. These dimensions are taken as a fair average between ordinary spans and those bolder reaches of greater length up to 300 feet, and even beyond, which are coming more into favor of late years. They are also the proportions of the iron bridge over Barren river, on the Louisville and Nashville Railroad, with the details of which the writer is familiar, he having been engaged on that road at the time of its erection.

As computing the strains upon a truss, the weight of the truss itself must be assumed in advance of its actual determination, the bridge just mentioned has been adopted as a standard of weight for the present purpose. This bridge is Fink's suspension truss, of the dimensions above given. The track is at the bottom of the truss, and the bridge contains 122,000 lbs. cast iron, 98,000 lbs. wrought iron, 50,000 lbs. lumber, making a total of 270,000 lbs., which, for convenience of division, will be called 272,000 lbs. The load uniformly distributed will be taken, as usual for railway bridges, at one ton (of 2240 lbs.) per linear foot, or 448,000 lbs., so that the total weight of bridge and load would be 720,000 lbs., of which the weight for each truss will be 360,000 lbs.

The number of panels of 12½ feet in length is 16, each therefore weighing unloaded 8,500 lbs., and with 14,000 lbs. of load added, 22,500 lbs. The position here assumed of the track at bottom of truss making an overgrade or through bridge, is disadvantageous to the Fink truss, as will be explained hereafter, when the effect of a change to the top of truss, making an undergrade bridge upon the several models will be treated of. The rolling weight brought upon the truss by the train, will consist of the heaviest engine used for slow freight transportation, and weighing 84,000 lbs., followed by a tender weighing some 42,000 lbs., and of cars such as are used in carrying coal, weighing so nearly the assumed ton per linear foot, that their falling short of that weight would about be made up by the engine.

This would not, however, be the weight of every train, the ordinary freight, and the passenger trains falling considerably within it. The engine referred to, rests 84,000 lbs. on eight drivers, all connected and with their four centres, all inside of 12½ feet or the length of one panel. The panel supports, then carry the weight of the engine plus the weight of one panel of truss, and must be graduated to resist this strain.

In the Fink and Bollman trusses, the weight of engine borne by each panel system is 42,000 lbs. minus the proportion of the load borne by the adjacent system on each side through the distributing influence of the railjoists. In the present case, taking into consideration the position of the drivers, and leverage of centre of gravity of each half of the load—one-eighth of the weight is carried in each direction, so that the load borne by the panel supports opposite the middle of the engine is 31,500 lbs.—To this add 8,500 lbs. weight of one panel of truss, and we have 40,000 lbs. as the extreme load for one set of panel supports. In the Murphy and Triangular trusses however, if the counter-tie in the panel next the rear of the engine is loose, then the one-eighth of the weight distributed to the rear is transferred back again to the acting system through the main panel tie, and accordingly in this case the weight of engine which can come on the supports of one panel is 42,000 minus one-eighth or 36,750 lbs. To recapitulate, in the Fink and Bollman trusses an engine can bring
upon one panel, ... 31,500 lbs.

In the Murphy and Triangular, ... 36,750 "
excepting in the case of the middle panel, where, as both panel ties must obviously be in adjustment, the weight will be the same as in the other trusses or 31,500 lbs.

The flooring systems will be considered as the same in all four trusses, and for this purpose of equalization the bill of material for the rail track of Barren River Bridge will be taken as common to all. This consists of 17,000 ft. B. M. of lumber, 30 floor truss rods, 1¼ inch section and 4 ft. long, and 30 girder plates weighing 60 lbs. each, and is believed to be fully as economical as any flooring on any of the existing examples of the trusses in question.

The sectional areas of the cast and wrought iron parts as hereafter determined, will be calculated in the computation of the weights, with the net lengths between the points of junction of the lines of compression and extension. To the results thus obtained, there will be added 15 per cent. for the wrought iron and 20 per cent. for the cast; the first being the necessary allowance for bolts, nuts, eyes and pins, and the latter for the joint thickenings and mouldings of the castings. These proportions are based upon the experience of the writer, who uses them habitually in his professional practice.

The wrought iron will seldom vary more than a few hundred lbs. from the total weights thus derived, but in the case of the cast iron, much of the correctness of the estimate depends upon the foundry where the work is done. Twenty per cent. however is the average allowance in cases where the castings are contracted for by the *pound*, but where in common parlance the "job is lumped," the writer has observed a curious propensity on the part of the cast iron to diminish in weight several per cent. below this standard.

In determining next the proportion of *safe* to *breaking* strain in the several parts, respect should be had to the frequency with which they are subjected to stress by the moving load, as this will manifestly influence their powers of endurance.

The primary system of a truss, that is, the system which upholds the entire truss when weighted with its maximum load from end to end, such as the chords of a Murphy or Triangular truss, or the main and secondary tension bars of a Fink bridge, may be safely subjected to a heavier strain than the tertiary and panel systems of the Fink, or the panel systems of the other trusses, the latter of which are fully strained by the engine leading every train, while to strain the primary systems to the utmost limit allowed, would require a train composed wholly of locomotives and their tenders.

For the quarternary system of the Fink, and middle panels of the other trusses, therefore a strain upon the wrought iron tension bars of 10,000 lbs. per square inch will be taken, as this is the generally assumed measure of safe stress, supposing it to be a *constant* one. For the tertiary system of the Fink and first four panels of the other trusses 11,000 lbs., and for the primary and secondary systems of the Fink, and the chords of the Murphy and Triangular, 12,000 lbs. per square inch will be adopted.

The Bollman truss being altogether a *panel* system of supports, the proportion proper to that system will be used for it, viz. 10,000 lbs. per square inch. For the calculation of the strength of the cast iron parts of the several trusses, (and notwithstanding the prejudice in Europe and to some extent in America against its use in bridges, it will be adopted in these comparisons for all parts in simple compression) Rankine's formula will be used, wherein $\frac{F\ A}{1 + \left(0025 \times \frac{l^2}{d^2}\right)} =$ breaking weight of column, in which F equals 80,000 lbs. or the crushing weight per square inch of a cylindrical column of cast iron; $\frac{l}{d} =$ unity; (i. e. length and diameter are equal) A equals area of section in square inches — l equals length in inches, and d equals diameter in same. The results from this formula are somewhat lower, but are more uniformly correct (especially where $\frac{l}{d}$ is less than 30) than those given by the formulæ of Barlow, Fairbairn or Hodgkinson, as the writer has ascertained by a thorough course of experiments on the subject. In proportioning the size of the cast iron parts, reference will be had to the exposure to vibration, the greater relative strength to resist this disturbing element, which a large casting possesses in comparison with a small one, and the sizes necessary to ensure good casting and to provide against breakage from sudden shocks or careless handling in erection. For the strength of chords and large posts, where the metal is 1 inch and over in thickness, and $\frac{l}{d}$ does not exceed 15, the proportions of the working load to ultimate strength will be 1-5

For posts, metal not less than $\frac{5}{8}$ nor $\frac{l}{d}$ more than 25, proportion, ... 1-7

For posts, metal $\frac{5}{8}$ or less, or $\frac{l}{d}$ exceeding 25, proportion from . . . . 1-10 to 1-40

The above principles and proportions are the results of much experience on the part of the writer in iron and wooden bridge construction, and they are here introduced with the view of making this a thoroughly practical and working analysis, and not merely a theoretical investigation.

In choosing a through or overgrade bridge, for the subject of the present analysis, the Bollman and Triangular trusses gain in the comparison—the first because the posts have then but the chord and tension bars to support, no weight being transmitted to the tops of the posts, and they may be proportionably lighter in consequence, and the second, because in the undergrade truss, it loses the advantage of having its main brace to constitute its pier tower, and necessitates means for carrying the rail joists, by additional support to the piers or abutments from the terminations of the upper chords.

In the Murphy there is also a gain as there is a difference in the load of each post of the weight of one panel in favor of the overgrade bridge. For instance, with 15 panels of the truss loaded and the engine at Post No. 1—this post in an undergrade bridge, would transmit the weight of the engine and transferred load behind the engine to the tie at its foot, while in an overgrade bridge, this tie would take this strain direct and not through the post, while the latter would only be the recipient of the strain from tie number 2, 3, &c. or would carry just one panel less than in the other case. This law holds good with all the posts in the bridge, as will be seen on examination.

With the Fink truss on the other hand there is a considerable comparative loss in economy of material in a "through" bridge, as in the ~~over~~grade the flooring suspension, and bracing systems are omitted; (the Triangular and Murphy trusses must have these braces in either case;) the posts can be shortened and owing to the support [illegible] of the bridge coming immediately under the top chord, (less base being therefore required than in the Triangular and Murphy systems, where the weight acting with a leverage equal to the depth of the truss, has a much greater tendency to produce lateral oscillation,) the distance between the chords can be narrowed and the bridge consequently cheapened. This last advantage is also possessed by the Bollman, but it does not counterbalance what is lost in other respects.

The overgrade bridge is thus, in the above aspect, most favorable to the Bollman, next so to the Triangular, next to the Murphy, and disadvantageous to the Fink truss.

Estimates of Material in the four Trusses respectively, upon the principles, and of the dimensions above given, viz. span 200 *feet—height of truss* 21 *feet—distance of Trusses apart* 18 *feet—measured in each case from centre to centre of chords*—16 *panels of* 12½ *feet each.*

In these estimates, the parts subject to compression, that is top chords, posts, struts and pier towers, of cast iron; tension bars and rods of all classes, pins and bolts, of wrought iron. The use of cast iron for the compressed parts of trusses is sanctioned by long and satisfactory experience in America, although the prejudice against it in England seems as inveterate as it is unnatural, considering that in the cases in which (as in the Dee Bridge) failure occurred from its use, the material was subjected to transverse strain, owing to injudicious proportioning and arrangement of parts. It is believed that where the cast iron of our bridge trusses has been of proper section and properly protected from all cross strains, it has been the safest element of the combination, and that all the failures that have occurred have been from fracture of the wrought iron tension rods from insufficient sectional area, bad iron or imperfect welding. To use wrought iron compressively from a vague and unfounded idea of its superior safety, is to reject a better and cheaper material for an inferior and dearer one, and this, there is little doubt, will be the final decision of Engineers here and in Europe. The complicated and costly modes of giving stiffness to resist compression to thin rolled iron plates which the dread of using cast iron in its place has led engineers to adopt, are remarkable instances of the power of preconceived notions.

FINK TRUSS.

Overgrade bridge 200 feet span—21 feet depth and 18 feet width of truss—16 panels 12½ feet each—cast iron pier towers.

In this bridge the tension and counter-tension bars being all of the same length and each system of supports comprising either one half of the next larger or embracing two of the next smaller systems, the principle of the truss as well as the manner of the computation of the strains is much simpler than any of its competitors.

Each post bears one-half the weight between the extremities of its supporting system and half of this again is borne by each tension bar attached to the post. Under this law the middle post supports one half the weight of one truss, the quarter post, one-fourth; the eighth post one-eighth; and the sixteenth post, one sixteenth of the same.

On the middle and quarter posts there can only be brought the regular load, viz. one ton per foot over the space occupied by their supporting systems, but with the other two posts the case is different. During the passage of an eight wheel connected engine, which with tender attached, weighs 63 tons and covers fifty-six feet, there is one moment when the eighth post bears

Proportion of weight of engine, ...	32,410 lbs.
" " tender, ...	8,400 "
" " truss, ...	17,000 "
Total, ...	57,810 lbs.
Or for convenience of calculation, say . . .	58,000 "

On the system supporting the sixteenth post, as has already been shown, the proportion of weight of engine will be,	31,500 lbs.
and weight of truss, ...	8,500 "
Making a total of, . . .	40,000 lbs.

This post itself bears only the weight of one panel of chord casting and one half the weight of the transverse strut connecting the chords.

Upon the above data the calculations and proportions following are based.

FINK TRUSS.

TABLE OF STRAINS AND WEIGHTS OF WROUGHT IRON PARTS.

No. of System.	No. of Panels borne by the Rods.	Weight borne by Rods.	Expression and Computation of Strains upon each System.	Strain on Tension Rods.	Strain allowed per square inch of Sectional Area.	Sectional Area of Tension Rods.	Lengths of Tension Rods.	No. of Tension Rods.	Weight per lineal foot of Rods.	Total Weight.	REMARKS.
1	8	180,000	$\frac{180,000\times102.2}{2\times21}$	438,000	12,000	36.5	102.2	4	124.1	50,756	
2	4	90,000	$\frac{90,000\times54.3}{2\times21}$	116,370	12,000	9.75	54.3	8	33.15	14,387	
3	2	58,000	$\frac{58,000\times27.2}{2\times10.5}$	75,124	11,000	7.	27.2	16	23.8	10,358	
4	1	40,000	$\frac{40,000\times16.3}{2\times10.5}$	31,050	10,000	3.1	16.3	32	10.54	5,497	
										80,998	
Suspension Links……………………				33,500		3.3	2	6	11.22	134	
Lateral Brace Rods…………………						1.25	23	64	4.2	6,182	
Long Suspension Links……………				33,500		3.3	10.5	24	11.22	2,827	
Floor Truss Rods……………………						1.25	4	30	4.2	510	
										9,653	

Sum total,………………………………………………… 90,651
Add 15 per cent. for bolts, nuts, eyes and pins,……. 13,597

Total weight of wrought iron in truss,………………104,248 lbs.

HORIZONTAL STRAIN ON CHORD.

The horizontal strain on the chord is uniform throughout, as in the case of the Bollman truss, and is equal to the sum of all the horizontal strains caused by the systems of tension rods taking hold at either end of the chord.

The expression of this strain for any system is $\frac{W\,P}{2\,h} = H$, in which W equals weight on post from regular uniform load, (which is one-half of the whole load on that system ;) P length of chord from junction of tension bar with chord to top of post ; h equals height of post and H horizontal strain in chord. A slight increase to the total chord strain thus determined takes place when the truss is fully loaded and the engine stands on the panel next the abutment, but this increase occurs only in the first panel section, and this has necessarily to be so much strengthened by the arrangements for the reception of the tension bars that further provision for this local strain would be unnecessary even were it much more than it is.

Estimate of horizontal strain in chord in round numbers :

System 1.	$\frac{180{,}000 \times 100}{21 \times 2} =$ . . .	429,000 lbs.
" 2.	$\frac{90{,}000 \times 50}{21 \times 2} =$ . . .	107,000 "
" 3.	$\frac{45{,}000 \times 25}{105 \times 2} =$ . . .	53,600 "
" 4.	$\frac{22{,}500 \times 12.5}{10.5 \times 2} =$ . . .	13,400 "
Total strain on chord,	. . .	603,000 lbs.

FINK TRUSS.

TABULAR ESTIMATE OF STRAINS AND CONSEQUENT PROPORTIONS AND WEIGHTS OF CAST IRON PARTS.

No. of Post or Chord.	Diameter of Column.	Thickness of Metal.	Extreme Strain.	Ultimate Strength.	Proportion of Strain to Strength.	Sec. Area in Square Inches.	Strain per Sq. Inch.	Length of Column.	No. of Columns.	Weight per Foot.	Total Weight.		REMARKS.
Chord	12	$1\frac{5}{8}$	603,000	3,041,750	1-5	52.9	11,400	12.5	32	164	65,596		
Main Post	12	1	180,000	1,330,000	1-7	35	5,000	21	2	108.5	4,557		
Quarter Post ...	9	1	90,000	650,000	1-7	25	3,500	21	4	77.5	6,510		
Eighth Post.....	6	$\frac{5}{8}$	50,000	402,800	1-8	10.6	5,000	10.5	8	32.86	2,760		
Sixteenth Post..	4	$\frac{1}{2}$	2,500	71,300	1-28	3.1	800	10.5	16	9.61	1,614		
											81,037		
										Add 20 per cent.	16,207	97,244	Total lbs. in chord and posts.
										17 cross struts, 300 lbs. each,	5,100		
										30 girder plates, 60 lbs. each,	1,800	6,900	
												104,144	Total lbs. in truss.
										4 pier towers, 5,650 lbs. each,		22,600	
												126,744	Total lbs. cast iron in bridge.

SYNOPSIS OF WEIGHTS.

Wrought iron in chain systems, ...	93,148 lbs.
“ bracing and flooring systems, . .	11,100 “
Total wrought iron in truss, ...	104,248 lbs.
Cast iron in chord and posts, ...	97,244 lbs.
“ “ in pier towers, ...	22,600 “
“ “ struts and flooring, ...	6,900 “
Total cast iron in truss, ...	126,744 lbs.
Total cast iron, ...	126,744 lbs.
“ wrought iron, ...	104,248 “
“ lumber, (17,000 ft.)	50,000 “
	280,992 lbs.
But as the cast iron pier towers are not borne by the truss, and were not included in the assumed weight, deduct,	22,600 “
Weight of truss proper, ...	258,392 “
“ assumed for calculation, ...	272,000 “
Surplus strength of truss as above proportioned,	13,608 “

ESTIMATE OF COST OF MATERIAL.

126,744 lbs. cast iron, @ 6 cts.	$ 7,604 64
104,248 lbs. wrought iron, @10 cts.	10,424 80
17,000 ft. lumber, @ 45\frac{00}{100}$	765 00
Total cost per span, ...	$18,794 44
Cost per foot lineal, ...	$ 93 97

MURPHY TRUSS.

Overgrade Bridge, 200 feet span ; 21 feet depth of truss ; width of do. 18 feet ; 16 panels, 12½ feet each ; cast iron pier towers.

STRAINS IN CHORDS.

To obtain these, the bridge will be considered as uniformly loaded throughout.

In this case, each tie has to carry the weight of truss and load between its junction, with the lower chord and the middle post, plus the weight of one-half panel between the said junction and the nearest abutment. For the resolution of the strains produced by this weight, the angle of tie with post will be considered, height of post equaling rad ; length of panel nat. tang., and length of diagonal tie equaling nat. secant ; then by parallelogram of forces W × tang. = horizontal strain in chord, and W × sec. = strain on tie.

The total stress in any panel of the chords, is the accumulated strain of all the ties between it and the nearest abutment.

To prove the results arising from the above computations, the standard formula $\frac{S \times W}{8h}$ (or span × weight, divided by 8 times the height of truss,) = horizontal strain in chord, at middle of bridge, will be used.

If the accumulated horizontal strains from the ties at middle post of bridge, and the product of this well known and proved formula agree, it is a certain proof of the correctness of the calculation of the strains in the different parts, the sum of which make up the whole strain at middle panel.

MURPHY TRUSS.

TABULAR ESTIMATE OF STRAINS AND WEIGHTS OF LOWER CHORD.

No. of Post or Tie.	No. of Panels borne by Tie.	Weight per Panel.	Weight supported at foot of Post.	Nat Tangent of Brace Angle.	Strains of Chord resulting from load borne by Tie.	No. of Panel.	Accumulated Panel Strains.	Strains allowed per square inch	Sectional Area of Chord in respective Panel.	Length of Tension Bars.	No of Tension Bars.	Weight per foot.	Total Weight.	REMARKS.
Brace Rods from foot of Pier Tower to foot of Post No. 1.									4.0	12.6	4	13.6	680	
1	7½	22,500	168,750 lbs.	0.595	100,406	2	100,406	12,000	8.5	"	"	28.9	1,445	
2	6½	"	146,250 "	"	87,019	3	187,425	"	15.6	"	"	53.04	2,652	
3	5½	"	123,750 "	"	73,631	4	261,056	"	21.75	"	"	73.95	3,697	
4	4½	"	101,250 "	"	60,243	5	321,299	"	26.75	"	"	90.95	4,547	
5	3½	"	78,750 "	"	46,856	6	368,155	"	30.70	"	"	104.38	5,219	
6	2½	"	56,250 "	"	33,469	7	401 624	"	33.47	"	"	113.8	5,689	
7	1½	"	33,750 "	"	20,081	8	421,705	"	35.1	"	"	119.34	5,967	
8	½	"	11,250 "	"	6,694		428,399							
Sum of weights,			720,000 lbs.	Of Strains.	428,399									This Strain is only felt in middle section of upper chord.

Strains in middle of chord by formula $\frac{S \times W}{8h} = \frac{200 \times 360,000}{21 \times 8} = 428,571$, thus proving the correctness of the foregoing; the slight discrepancy being due to the fact, that the fractional expression of the tangent of tie angle is not carried out to a greater number of decimals.

Total	29,896
Add 15 per cent	4,484
Total wrought iron in chord,	34,380

POSTS AND TIES.

To obtain the strains on these, the effect of a partial load on the bridge must be considered. In the ordinary mode of computation, the load borne by a panel tie or brace, is assumed to be the weight of truss and load between it and the middle post. This is true only when the bridge is fully and uniformly loaded, but when the train extends only to the middle and beyond, the ties between the engine and the unloaded abutment, have to transmit to the latter its proportion of the rolling weight, the amount of this, of course, being determined by the position and consequent leverage of the centre of gravity of the load. With one-half the bridge loaded, and the engine opposite the middle post, the farther panel tie must support, first, its share of weight of truss, next, one-half the weight of engine, and lastly, the transferred weight to be borne by the unloaded abutment. As the train proceeds over the bridge, this law applies to each tie in succession, the centre of gravity advancing half a panel as the engine moves a full one, until they respectively reach the middle of the bridge and the farther abutment, at which point the strains according to both methods of calculation finally coincide. In addition to this strain, if a counter-tie happens to be loose, (which in this form of truss is certain to be the case on a hot day,) the opposite main-tie has to sustain the entire weight of the engine, a contingency which must be provided for in the formulary expression of the strain. For the middle panel tie, consequently, the equation is, $\left(\frac{e+t}{2}\right) + \left(14{,}000 \text{ lbs.} \times \left(P \times \frac{g}{16}\right) = S\right.$, in which $e =$ weight of engine; "t" $=$ weight of portion of truss borne by tie; 14,000 lbs. $=$ weight per panel of rolling load; $P =$ number of panels between *rear of engine* and loaded abutment; $g =$ No. of panels between centre of gravity of P and same abutment, and $16 =$ whole No. of panels. For the ties beyond the middle, the expression becomes $(e + t) + \left(14{,}000 \times \left(P \times \frac{g}{16}\right)\right.$ (the last may be rendered $\left(\frac{P^2}{32}\right) = S$, and for the counter-ties, as they bear no part of the weight of the truss, (the main tie being always necessarily in adjustment, and consequently ready to bear its half of the weight of the engine,) $\frac{e}{2} + 14{,}000 \times \left(\frac{P^2}{32}\right) = S$.—These last are only calculated from the abutment to the middle post. For reasons already given, e is for middle panel, 31,500 lbs.—for side panels, 36,750 lbs.

Theoretically, the counter-ties begin to act at the middle of the bridge and successively become main-ties moving towards the advancing load, as the shifting centre of gravity of the train and loaded portion of the truss renders it necessary to transfer to the unloaded abutment a sufficient portion of the weight of the unloaded part of the truss to preserve an equilibrium of horizontal strains in the chords. In other words, through this action of the counter-ties, the virtual centre of the bridge is shifted towards the load at the rate required by the relative weights and leverage of the centres of gravity of the two opposite portions of the truss, on each side of this moving centre, to keep the truss in equilibrio.

In point of strict theory, therefore, no counter-ties are required between the loaded abutment and that panel where the load and this shifting span centre at length meet, and between this point of meeting and the actual middle of the bridge the weight on the counter-tie is the transferred weight due to its position, less the weight of that portion of the truss between the counter-tie in question and the middle post. In practice however, owing to bad workmanship, defective adjustment, etc., the results given by the foregoing equation are by no means greater than are necessary for spans of 200 ft. and under. Beyond this, as the span increases and the relative weight of the load becomes less in proportion to that of the truss, the counter-ties may be reduced more nearly to their theoretical dimensions, and in very large bridges they may be omitted altogether in the panels nearest the abutments.

In the following computations of strains the multiplier is carried out to but one decimal, as there is no necessity for the strain to be calculated within less than one thousand lbs. of the exact figure for the purpose of proportioning the parts.

MURPHY TRUSS.

TABULAR ESTIMATE OF STRAINS AND CONSEQUENT PROPORTIONS AND WEIGHTS OF CAST IRON PARTS.

No. of Post or Panel of Chord.	Diameter of Column.	Thickness of Metal.	Extreme Strain from partial load.	Ultimate Strength of Column.	Proportion of Strain to Strength.	Sectional Area in sq. inches.	Strain per square inch.	Length of Column.	No. of Columns.	Weight per foot.	Total Weight.	REMARKS.
Panel No. 8—Chord.	12	1¼	428,399	2,163,000	1-5	42	10,000	12½	4	130.2 lbs.	19,530	These three sections cast same size for convenience of joints.
" " 7 "	"	"	421,705	"	"	42	10,000	"	4	" "		
" " 6 "	"	"	401,624	"	"	42	9,500	"	4	" "		
" " 5 "	12	1	368,155	1,902,000	"	35	10,000	"	4	108.5 "	10,850	
" " 4 "	"	"	321,299	"	"	35	9,000	"	4	" "		
" " 3 "	12	⅞	261,056	1,782,000	1-7	31	8,400	"	4	96.1 "	9,610	
" " 2 "	"	"	187,425	"	1-8	31	6,000	"	4	" "		
" " 1 "	12	¾	100,406	1,495,000	1-15	26	4,000	"	4	80.6 "	4,030	
Post No. 1	12	1	171,738	1,330,000	1-7	35	5,000	21	4	108.5 "	9,114	Vertical strain on side panel posts is that of the tie attached to its head.
" " 2	12	⅞	151,750	1,178,000	1-7	31	5,000	"	4	96.1 "	8,072	
" " 3	12	¾	132,960	988,000	"	26	5,300	"	4	80.6 "	6,770	
" " 4	10	1	114,716	883,500	"	28.5	4,000	"	4	88.3 "	7,417	Ditto on middle post, that produced by counter-tie similarly attached.
" " 5	10	⅞	96,700	775,000	1-8	25	4,000	"	4	77.5 "	6,510	
" " 6	9	⅞	80,440	599,800	"	22.3	3,600	"	4	69.1 "	5,804	
" " 7	9	¾	44,600	504,400	1-9	19.4	3,000	"	4	60.1 "	5,048	
" " 8	9	⅝	36,848	426,000	1-11	16.4	2,500	"	2	50.8 "	2,139	

	Total Weight.	REMARKS.
	94,886	
Add 20 per cent...	18,977	
	113,863	Total lbs. in chords and posts.
17 cross struts, 300 each.........................5,100 30 girder plates 60 each...........................1,800	6,900	
	120,763	Total lbs. in truss.
4 pier towers, 5,650 each.......................................	22,600	
	143,363	Total lbs. cast iron in bridge.

TABULAR ESTIMATE OF STRAINS PRODUCED IN TIES AND COUNTER-TIES BY PARTIAL LOAD, AND CONSEQUENT PROPORTIONS AND WEIGHTS OF WROUGHT IRON PARTS.

Position of Middle Driver of Engine.	Expression and Computation of Weight at foot of each Post respectively at the moment of passage of Engine with Train attached.	Weight at foot of Post.	Secant of Tie Angle.	Strain on Tie or Counter Tie.	Strain allowed per square inch.	Sectional Area of Tie or Counter Tie.	Length of Tension Rods.	No. of Tension Rods.	Weight per foot.	Total Weight.	REMARKS.
	$\frac{e}{2}$ t p g				lbs.	″					
Post No. 8	$15,750 + 4,250 + (14,000 \times 7.5 \times \frac{3.75}{16})$	44,600	1,167	50,950	10,000	5.1	24.5	4	17.34	1,700	e = 31,500 lbs. here.
" " 7	$36,750 + 12,750 + (14,000 \times 8.5 \times \frac{4.25}{16})$	81,000	1,167	93,847	10,000	9.4	24.5	"	31.96	3,132	e = 36,750 lbs. for this and all side panels.
" " 6	$36,750 + 21,250 + (14,000 \times 9.5 \times \frac{4.75}{16})$	97,000	1,167	112,817	10,000	11.3	"	"	38.42	3,765	
" " 5	$36,750 + 29,750 + (14,000 \times 10.5 \times \frac{5.25}{16})$	114,716	"	133,835	11,000	12.2	"	"	41.48	4,065	
" " 4	$36,750 + 38,250 + (14,000 \times 11.5 \times \frac{5.75}{16})$	132,960	"	155,120	"	14.1	"	"	47.94	4,698	Main Ties.
" " 3	$36,750 + 46,750 + (14,000 \times 12.5 \times \frac{6.25}{16})$	151,750	"	177,042	"	16.1	"	"	54.74	5,365	
" " 2	$36,750 + 55,250 + (14,000 \times 13.5 \times \frac{6.75}{16})$	171,758	"	200,384	"	18.2	"	"	61.88	6,065	
" " 1	$36,750 + 63,750 + (14,000 \times 14.5 \times \frac{7.25}{16})$	192,359	"	224,419	"	20.3	"	"	69.02	6,764	
" " 7	$18,375 + (14,000 \times 6.5 \times \frac{3.25}{16})$	36,848	"	42,989	10,000	4.3	"	"	14.62	1,433	
" " 6	$18,375 + (14;000 \times 5.5 \times \frac{2.75}{16})$	31,619	"	36,889	"	3.7	"	"	12.58	1,233	
" " 5	$18,375 + (14,000 \times 4.5 \times \frac{2.25}{16})$	27,258	"	31,801	"	3.2	"	"	10.88	1,076	
" " 4	$18,375 + (14,000 \times 3.5 \times \frac{1.75}{16})$	23,716	"	27,668	"	2.8	"	"	9.52	933	Counter-Ties.
" " 3	$18,375 + (14,000 \times 2.5 \times \frac{1.25}{16})$	21,105	"	24,623	"	2.5	"	"	8.5	833	
" " 2	18,375	18,375	"	21,437	"	2.1	"	"	7.14	700	
" " 1	18,375	18,375	"	21,437	"	2.1	"	"	7.14	700	
" " 0				15,000	"	1.5	"	"	5.10	500	
										42,962	
									Add 15 per cent,	6,443	49,405, total in Ties and Counter-Ties.
Suspension links					10,000	3.3	2.	30	11.22	673	
Lateral brace rods					"	1.25	23	64	4.2	6,182	
Floor truss rods					"	1.25	4	30	4.2	510	
										7,365	
									Add 15 per cent.	1,105	8,470

Total wrought iron in ties, counter-ties, and bracing systems, 57,875.

MURPHY TRUSS.

WEIGHTS OF MATERIALS—SYNOPSIS.

Wrought iron in chord, ...	34,380 lbs.
“ “ ties and counter ties, . .	49,405 “
“ “ flooring and bracing systems, .	8,470 “
Total wrought iron in bridge, . . .	92,255 lbs.
Cast iron in chord and posts, ...	113,863 lbs.
“ pier towers, ...	22,600 “
“ struts and flooring, . . .	6,900 “
Total cast iron, ...	143,363 lbs.
Total wrought iron in bridge, ...	92,255 lbs.
“ cast “ “	143,363 “
“ lumber (17,000 ft. B. M.) . . .	50,000 “
	285,618 lbs.
Deduct for pier towers, they not being carried by truss, ...	22,600 “
Weight of truss proper, ...	263,018 lbs.
Assumed weight of truss in calculation, .	272,000 “
Surplus strength of bridge, . . .	8,982 lbs.

ESTIMATE—COST OF MATERIALS.

92,255 lbs. wrought iron, @ 10 cts. . . .	$ 9,225 50
143,363 “ cast “ @ 6 cts. . . .	8,601 78
17,000 ft. B. M. lumber, @ $ 45 00 . .	765 00
Total cost, per span, ...	$18,592 28
Cost per lineal foot, ...	$ 92 96

TRIANGULAR TRUSS.

Over-grade bridge, 200 ft. span, 21 ft. depth of truss, 18 ft. width of truss, 8 panels 25 ft. each, but with chords and flooring braced and supported at every $12\frac{1}{2}$ ft.

STRAINS.

These are the same in all parts as in the Murphy, as is also the method of computation. Every alternate tie in the first named truss, is matched by an inclined brace in the Triangular standing at the same angle, and resisting the same amount of strain, but with the direction reversed both of strain and angle; while the other set of ties is the same in both bridges. These inclined braces thus take the places of *all* the posts and every *alternate* tie in the Murphy bridge, and from their position in the framing become positive and active agents in the transmission of strains from the middle of the bridge towards the abutments and in the compensation of the truss, instead of fulfilling the merely negative duty of acting as straining beams between the chords, as in the case of the posts of the Murphy, Linville, Whipple and other Beam trusses. The panels being double the length of those in the Murphy truss, the diminution of strains in the chords takes place at one half the number of intervals, and consequently there will be a gain in the upper chord of the Triangular, amounting to the half-panel decrement in each panel, and the same loss in the lower chord, as compared with the Murphy. In the following tabular estimate, however, the sizes of the castings of the upper chord are made the same as in the Murphy truss, although the strain is less, as above stated: while the Murphy retains its advantage in the lower chord in the lesser quantity of wrought iron. Owing to the length of the panel, the rail joist is supported by a suspension link, and the upper chord by a six inch cast iron post (No. 5) in the middle of the panel span. This post is movable both at top and foot.

TRIANGULAR TRUSS.

TABULAR ESTIMATE OF STRAINS, WEIGHTS AND PROPORTIONS OF WROUGHT IRON CHORD.

No. of Brace or Tie.	No. of Panels borne by brace or tie.	Weight per Panel.	Weight supported at foot of Posts.	Natural Tangent of Brace angle.	Strains in Chord from each Brace or Tie.	No. of Panels.	Accumulated Strains	Strains allowed per square inch.	Sectional area of Chord in each Panel.	Length of Tension Bars.	No. of Tension Bars.	Weight per foot.	Total Weight.	REMARKS.
Brace 1	3¾	22,500	168,750	0.595	100,406	1	100,406	12,000	8.5	25	4	28.9	2,890	
Tie... 1	3¼	"	146,250	"	87,019	C	187,425							Strain in upper chord.
Brace 2	2¾	"	123,750	"	73,631	2	261,056	12,000	21.75	25	4	73.95	7,395	
Tie... 2	2¼	"	101,250	"	60,243	C	321,299							" " " "
Brace 3	1¾	"	78,750	"	46,856	3	368,155	12,000	30.70	25	4	104.38	10,438	
Tie... 3	1¼	"	56,250	"	33,469	C	401,624							" " " "
Brace 4	¾	"	33,750	"	20,081	4	421,705	12,000	35.1	25	4	119.34	11,934	
Tie... 4	¼	"	11,250	"	6,694	C	428,399							" " " "
	Sum of weights,		720,000	Strains,	428,399								32,657	

Strains in middle of chord by formula $\frac{S \times W}{8h} = \frac{200 \times 360,000}{21 \times 8} = 428,571$, thus proving the correctness of the foregoing, the slight discrepancy being due to the fact that the fractional expression of the tangent of the tie angle is not carried out to a greater number of decimals.

Add 15 per cent........................... 4,898

Total wrought iron in chord..........37,555 lbs.

TRIANGULAR TRUSS.

TABULAR ESTIMATE OF STRAINS PRODUCED IN TIES AND COUNTER-TIES BY PARTIAL LOAD, AND CONSEQUENT PROPORTIONS AND WEIGHTS OF WROUGHT IRON PARTS.

Position of Middle Driver of Engine	Expression and Computation of Weights at foot of each Post respectively, at moment of passage of Engine with train attached.	Weight at foot of Post.	Secant of Tie Angle	Strain on Tie or Counter-tie.	Strain allowed per square inch.	Sectional Area of Tie or Counter-tie.	Length of Tension Rods.	No. Tension Rods.	Weight per foot.	Total Weight.		REMARKS.
Tie No. 4.....	$15,750 + 4,250 + (28,000) \times \left(\frac{3.75^2}{16}\right)$	44,600	1,167	50,950	10,000	5.1	24.5	4	17.34	1,700		
" " 3.....	$36,750 + 21,250 + (28,000) \times \frac{4.75^2}{16}$	97,000	"	112,817	10,000	11.3	"	"	38.42	3,765		
" " 2.....	$36,750 + 38,250 + (28,000) \times \frac{5.75^2}{16}$	132,960	"	155,120	11,000	14.1	"	"	47.94	4,698		
" " 1.....	$36,750 + 55,250 + (28,000) \times \frac{6.75^2}{16}$	171,758	"	200,384	11,000	18.2	"	"	61.88	6,065		
Counter-tie 3	$18,375 + (28,000) \times \frac{2.75^2}{16}$	31,619	"	36,889	10,000	3.7	"	"	12.58	1,233		Counter-tie passes through middle of inclined brace.
" 2	$18,375 + (28,000) \times \frac{1.75^2}{16}$	23,716	"	27,668	10,000	2.8	"	"	9.52	933		
" 1	18,375	18,375	"	21,437	10,000	2.1	"	"	7.14	700		
	Add 15 per cent.............									19,094 2,864	21,958	lbs. in ties and counter-ties.
	Long suspension links..			33,500	10,000	3.3	22	16	11.22	3,949		
	Short do. do.			33,500	10,000	3.3	2	14	11.22	314		
	Lateral brace rods..					1.25	23	60	4 2	5,796		
	Floor truss do.					1.25	4	30	4.2	510		
	Diagonal brace rods..					.78	23	30	2.7	1,863		
	Add 15 per cent.............									12,432 1,864	14,296	lbs. in bracing, flooring, and suspension systems.

Total wrought iron in ties and flooring..........................36,254

TRIANGULAR TRUSS.

TABULAR ESTIMATE OF STRAINS AND WEIGHTS, AND CONSEQUENT PROPORTIONS OF CAST IRON PARTS.

No. of Post or Chord Panel.	Expression and Computation of Strains on Posts.	Secant of Tie Angle	Diameter of Column	Thickness of Metal.	Strain on Column.	Ultimate Strength.	Strain to Strength.	Sectional Area.	Strain per square inch.	Length of Column.	No. of Columns.	Weight per foot.	Total Weight.	
Post No. 1	$36,750 + 63,750 + \left(28,000 \times \frac{7.25^2}{16}\right)$	1,167	12	$1\frac{1}{2}$	224,419	1,575,860	1-7	49.4	4,500	24.5	4	153.14	15,008	
" " 2	$36,750 + 46,750 + \left(28,000 \times \frac{6.25^2}{16}\right)$	"	12	$1\frac{3}{16}$	177,042	1,285,570	1-7	40.3	4,500	24.5	4	124.93	12,243	
" " 3	$36,750 + 29,750 + \left(28,000 \times \frac{5.25^2}{16}\right)$	"	12	$\frac{7}{8}$	133,835	978,900	1-7	31.	4,500	24.5	4	96.10	9,418	
" " 4	$36,750 + 12,750 + \left(28,000 \times \frac{4.25^2}{16}\right)$	"	12	$\frac{3}{4}$	93,847	834,800	1-9	26.4	3,500	24.5	4	81.84	8,021	
" " 5		"	6	$\frac{1}{2}$	2,500	128,760	1-50	8.7	300	21.0	14	26.97	7,929	
													52,619	
									Add 20 per cent				10,524	63,143
Chord Panel No. 1			12	$\frac{7}{8}$	187,425	1,782,000	1-8	31.	6,000	25.	4	196.1	9,610	
" " " 2			12	1	321,299	1,902,000	1-5	35	9,000	"	4	108.5	10,850	
" " " 3			12	$1\frac{1}{4}$	401,624	2,163,000	1-5	42	9,500	"	4	130.2	13,020	
" " " 4			12	$1\frac{1}{4}$	428,399	2,163,000	1-5	42	10,000	"	2	130.2	16,510	
													39,990	
										Add 20 per cent			7,998	47,988
	Total in posts and chord,													111,131
19 cross struts, 300 lbs each													5,700	
4 pier bed plates, 550 lbs. each													2,200	
30 girder plates, 60 lbs. each													1,800	9,700
	Total cast iron in bridge													120,831

TRIANGULAR TRUSS.

WEIGHTS OF MATERIALS—SYNOPSIS.

Wrought iron, in chord,	37,555 lbs.
“ “ in ties and counter-ties,	21,958 “
“ “ flooring and bracing systems,	14,296 “
Total wrought iron, in bridge,	73,809 lbs.
Cast iron, in chord and posts,	111,131 lbs.
“ “ in flooring and struts,	9,700 “
Total cast iron, in bridge,	120,831 lbs.
Total cast iron,	120,831 lbs.
“ wrought iron,	73,809 “
“ lumber, (17,000 ft.)	50,000 “
	244,640 lbs,
Deduct for pier bed plates, which are not borne by truss.	2,200 “
	242,440 lbs.
Assumed weight of truss,	272,000 “
Surplus strength,	29,560 lbs.

ESTIMATE OF COST.

120,831 lbs. cast iron, @ 6 cts.	$ 7,249 86
73,809 “ wrought iron, @ 10 cts.	7,380 90
17,000 ft. B. M. lumber, @ $ 45 00	765 00
	$ 15,395 76
Cost per ft. lineal,	$ 76 98

BOLLMAN TRUSS.

Over-grade bridge, 200 feet span, 21 feet depth of truss, 18 feet width of truss, 16 panels $12\frac{1}{2}$ feet each, cast iron pier towers.

From the peculiar principle of this Truss, viz. the direct transfer of all strains to the chord at the abutments, each panel with its separate supporting system at every post is separately and successively exposed to the extreme load of 40,000 lbs.

The strains caused in the tension and counter-tension rods supporting each panel, will then be expressed in the case of the tension rod by the equation $\frac{W \times P}{16} \times \frac{l}{21} = S$, and $\frac{W \times (16-P)}{16} \times \frac{l}{21} = S$ for the counter-tension rod. In the foregoing, $W = 40,000$ lbs ; $P =$ No. of panels traversed by long or counter-tension rod ; $16 =$ whole No. of panels ; $l =$ length of rod, and $21 =$ depth of truss in feet.

TABLE OF STRAINS AND WEIGHTS OF WROUGHT IRON PARTS.

No. of Tension and Counter-tension Bar.	No. of Panels borne by Bars.	Weight borne by Bars.	Expression and Computation of Strains upon each System.	Strain on Tension and Counter-tension Bars.	Strain allowed per sq. inch of Sectional Area of Bars.	Sectional Area of Bars.	Length of Bars.	No. of Bars.	Weight per lineal foot of Bars.	Total Weight of Bars.	REMARKS.
1, S	15-16	40,000	$\frac{40{,}000 \times 15}{16} \times \frac{24.5}{21}$	43,750	10,000	4.4	24.5	4	15.0	1,470	
1, L	1-16		$\frac{40{,}000 \times 1}{16} \times \frac{188.8}{21}$	22,476	"	2.3	188.8	4	7.8	5,890	
2, S	14-16	40,000	$\frac{40{,}000 \times 14}{16} \times \frac{33}{21}$	55,000	"	5.5	33.	4	18.7	2,468	
2, L	2-16		$\frac{40{,}000 \times 2}{16} \times \frac{176.3}{21}$	42,583	"	4.3	176.3	4	14.6	10,295	
3, S	13-16	40,000	$\frac{40{,}000 \times 13}{16} \times \frac{43}{21}$	66,550	"	6.7	43.	4	22.8	3,921	
3, L	3-16		$\frac{40{,}000 \times 3}{16} \times \frac{164}{21}$	58,574	"	5.9	164.	4	20.1	13,185	
4, S	12-16	40,000	$\frac{40{,}000 \times 12}{16} \times \frac{54.3}{21}$	77,574	"	7.8	54.3	4	26.5	5,756	
4, L	4-16		$\frac{40{,}000 \times 4}{16} \times \frac{151.5}{21}$	72,150	"	7.3	151.5	4	24.8	15,029	
5, S	11-16	40,000	$\frac{40{,}000 \times 11}{16} \times \frac{66}{21}$	86,438	"	8.6	66.	4	29.2	7,708	
5, L	5-16		$\frac{40{,}000 \times 5}{16} \times \frac{139}{21}$	82,738	"	8.3	139.	4	28.2	15,679	
6, S	10-16	40,000	$\frac{40{,}000 \times 10}{16} \times \frac{78}{21}$	92,857	"	9.3	78.	4	31.6	9,859	
6, L	6-16		$\frac{40{,}000 \times 6}{16} \times \frac{126.8}{21}$	90,571	"	9.1	126.8	4	30.9	15,672	
7, S	9-16	40,000	$\frac{40{,}000 \times 9}{16} \times \frac{90}{21}$	96,429	"	9.6	90.	4	32.6	11,736	
7, L	7-16		$\frac{40{,}000 \times 7}{16} \times \frac{114.5}{21}$	95,417	"	9.5	114.5	4	32.3	14,793	
8 cwt.	8-16	40,000	$\frac{40{,}000 \times 8}{16} \times \frac{102.2}{21}$	97,333	"	9.7	102.2	4	33.	13,490	

Weight of tension rods = 146,951

Add for bolts, nuts, eyes and pins, 15 per cent. 22,042 | 168,993

Suspension links..	40,000	10,000	4	2.	30	13.6	816
Lateral brace rods..	....	"	1.23	23.	64	4.2	6,182
Panel brace rods..	....	"	1.25	24.5	64	4.25	6,664
Floor beam truss rods..	....	"	1.25	4.	30	4.25	510

14,172

Add for bolts, nuts, eyes and pins, 15 per cent, 2,126 | 16,298

Total weight of wrought iron = | 184,291

HORIZONTAL STRAIN IN CHORD.

The horizontal strain on the upper chord of this truss is the sum of all the strains produced by the tension rods attached to either end of the truss. The strain from any one tension bar is $\frac{S \times P}{l}$ = strain in chord, in which S = strain on rod, P = length of chord from abutment to post, and l = length of rod. Substituting therefore the previously ascertained quantities in the foregoing equation we have for

HORIZONTAL STRAINS.

			Pounds.
System 1	$= \frac{43{,}750 \times 12.5}{24.5} = 22{,}321 \times 2$	[Sys. 15 being equal to Sys. 1]	= 44,642
" 2	$= \frac{55{,}000 \times 25}{33} = 41{,}666 \times 2$	[Sys. 14 " " " 2]	= 83,332
" 3	$= \frac{66{,}550 \times 37.5}{43} = 58{,}038 \times 2$	[Sys. 13 " " " 3]	= 116,076
" 4	$= \frac{77{,}574 \times 50}{54.3} = 71{,}430 \times 2$	[Sys. 12 " " " 4]	= 142,860
" 5	$= \frac{86{,}438 \times 62.5}{66} = 81{,}\ 854 \times 2$	[Sys. 11 " " " 5]	= 163,708
" 6	$= \frac{92{,}857 \times 75}{78} = 89{,}285 \times 2$	[Sys. 10 " " " 6]	= 178,570
" 7	$= \frac{96{,}429 \times 87.5}{90} = 93{,}750 \times 2$	[Sys. 9 " " " 7]	= 187,500
" 8	$= \frac{97{,}333 \times 100}{102.2} = 95{,}238$	[Sys. 8, Central System]	= 95,238
			1,011,926

The horizontal strain on chord with tension bars, calculated to extreme load, due to weight of engine on each post or panel successively, is therefore = 1011,926 lbs., but as the strain produced on the chord by the assumed regular load of one ton per lineal foot over the whole chord is what is now required.

Then $\frac{1011{,}926 \times 22{,}500}{40{,}000} = 569{,}208$ lbs., which is the true strain on chord.

By deriving the horizontal strain direct from the formula $\frac{W \times L}{h} = H$, in which W = proportional weight on post borne by tension bar in question; L = distance between end of chord and head of post, and h = height of post, we have H = 569,109 lbs., which affords both a test and a proof of the accuracy of the preceding calculations of both tensile and compressive strains.

VERTICAL STRAIN ON POSTS.

The post in the Bollman bridge has to support its own weight, the weight of one panel of chord, and one half the weight of the transverse strut connecting the chords of the two trusses, together with $\frac{1}{32}$ part of the total weight of the tension bars, and must, in addition, be capable of withstanding the great vibration of the tension bars, when they are numerous, and the length of the span considerable, as well as to resist any accidental strain from the panel rods when the bridge is out of adjustment from the effects of temperature. The seemingly large relative strength which is given them by the proportions assumed in the accompanying calculations is necessary to ensure a good casting of that length and to resist the vibratory action of the truss.

TABLE OF STRAINS AND WEIGHTS, CAST IRON PARTS.

Chord and Posts.	External Diameter of Casting.	Thickness of Metal.	Extreme Strain in Pounds.	Ultimate Strength in Pounds.	Proportion of Strain to ult. Strength.	Sectional Area in square inches.	Strain per square inch.	Length of Column.	No. of Columns.	Weight per lineal foot.	Total Weight.
Chord.....	12″	1½″	569,208	2,903,750	1-5	50.5″	11,200	200′	2	156.5	62,600
Posts......	7″	½″	7,588	193,800	1-25	10.2″	744	21	30	31.6	19,920

	82,520
Add 20 per cent for mouldings and joints..	16,504
Total in chord and posts..	99,024
17 cross struts, between top chords, 300 lbs. each....................................	5,100
30 girder plates, 60 lbs. each, (a bearing for girders at foot of suspension link,)	1,800
Total weight cast iron in truss................................	105,924
Add 4 pier towers, 5,650 lbs. each..	22,600
Total weight cast iron in bridge...............................	128,524

SYNOPSIS OF RESULTS.

Total weight cast iron in bridge, . .	=	128,524 lbs.
Total weight wrought iron in bridge, .	=	185,291 "
Total weight lumber, (17,000 F., B. M.)	=	50,000 "
Total weight of bridge,		363,815 lbs.
But as pier towers are not borne by truss, deduct		22,600 "
Weight of truss proper. .	=	341,215 "
Assumed weight of truss in calculation, .	=	272,000 "
Deficiency of strength by surplus material,	=	69,215 lbs.

ESTIMATE OF COST.

Wrought iron, 185,291 lbs., @ 10 cts. . .	$18,529	10
Cast iron, 128,524 lbs., @ 6 cts. . . .	7,711	44
Lumber, 17,000 ft. B. M., @ $45, . .	765	00
Total cost per span, . .	$27,005	54
Cost per lineal foot, . .	$ 135	02

The preceding calculation of sectional area and weights assume that the long bars of each system are proportioned, in area to the smaller strains they bear. But the Bollman truss, as the writer is informed, is usually constructed in practice with the two rods of each system equal in sectional area, to obviate, in a degree, the disturbing effects (from extension under strain) of the inequality in their lengths. There should, therefore, be the proper correction made for this practice, recognized and adhered to as it appears to be by the authorized builders of this truss. It is probable that in this case that the section of the long chain is increased to the size of the short one, as a diminution of the latter or an average of the two would increase the strain per square inch to an unsafe degree in the short chain.

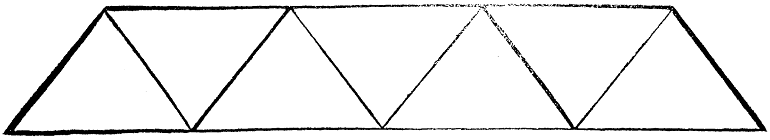
The writer has also learned that the premium design presented at the St. Louis competition lately invited by the North Missouri Railroad Company, had a depth of truss for a 200 ft. span of 28 ft. and a length of panel of 17 ft. The object of extending the panel so much beyond the usually adopted length must have been to lessen the accumulation of rods at the ends of the chords. This may be necessary to permit the extension of this truss to 200 ft. span, but it must involve an expensive rail joist, a considerably increased metal section in the chords, and cannot influence the present comparison favorably to this form of truss.

Make the same change of depth, and length of panel in the other trusses, and all three would still maintain their relative positions with the Bollman as to cost and strength. The Murphy, in fact, would be a gainer by the change.

The Bollman truss, with 200 ft. span, 28 ft. depth of truss and 17 ft. panel, may be as cheap as a Murphy or a Fink truss of the same span with 21 ft. depth of truss and 12½ ft. panel, but it is not nearly as cheap a bridge as either of these would be were they changed to the same proportions. In the foregoing estimate the writer has considered the panel bracing simply as panel rods intended to guard against the rising of the chord under a partial load and has proportioned them accordingly, deeming it a useless expenditure of material to enlarge them to the necessary sectional area to make of them a distributive system, as they cannot act as such excepting when the condition of the temperature is the same as when they were first adjusted.

The several trusses will next be considered, in their relative actions under changes of temperature or moving trains causing compressions and extensions of their several parts. The accompanying diagrams will illustrate this part of the subject.

THE TRIANGULAR TRUSS.

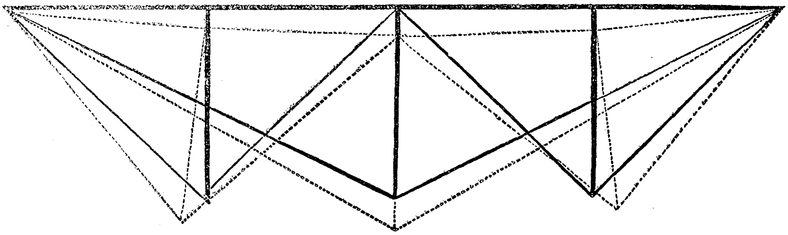


This truss, as is seen, consists of a series of triangles, which under a uniformly distributed load at rest, have one side compressed and two extended, or two compressed and one extended, according as their vertices point upwards or downwards, and by the principle inherent in the truss are invariably so strained, excepting in the case of the ties and braces nearest the middle, *in which the strains may be reversed when a partial load, covering less than one-half the bridge,* *produces a greater stress in the upper chord and in the supports of the panel on which the engine is standing, than the counter-stress caused by the weight of the opposite portion of the truss not yet covered by the train.* The exact point where this reversion of the direction of the forces in the ties and braces takes place is that where the weight of the partial load, added to the weight of the loaded portion of the truss, acting with a leverage equal to the distance of the centre of gravity of their combined weights from the loaded abutment, produces a horizontal strain in the upper chord equal to that caused by the weight of the unloaded portion of the truss acting with a leverage due to the distance of *its* centre of gravity from the *unloaded* abutment. These strains, however, are provided for in construction by the use of counter-ties and braces at these points, and as all the connections of chords, ties and braces are made by means of cylindrical pins, and therefore freely movable, all the systems adjust themselves to the partial stress of every passing load without strain upon the joints, and with equal facility to changes of temperature. The "Newark Dyke Bridge" of 297 feet span, is built on this principle, and is regarded, as perhaps, the most perfect truss in England.

THE FINK TRUSS.

The compensation of this truss is still more complete than that of the Triangular, embodying as it does the same principle in a form which gives the parts more freedom of action to elongate or contract independently of each other, under the stress of moving loads or change of temperature.

Figure 2.



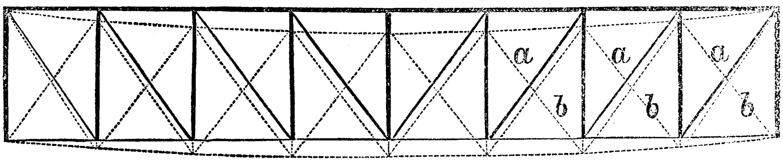
It will be seen that should the truss be deflected as shown by the dotted lines from a load or the effect of temperature, the feet of the posts being free to move, they have maintained their position, normal to the curve of the chord, and the distance from foot of post to point of suspension, is relatively the same, and the truss is equally strong and in as good adjustment as before deflection took place.

This is manifestly true of an undergrade truss, and not less so in the case of the overgrade ; as in the latter, the floorway is suspended from the feet of the posts by compensating suspension links, which permit free motion of the feet of the posts as before.

MURPHY TRUSS.

The compensating principle in this truss, is much less perfect than in either of the two preceding ones.

Figure 3.



In Figure 3, in the event of a settling of the truss from the effects of temperature, (the wrought iron bottom chord, expanding more than the top chord of cast iron, both from the greater expansibility of the material, and its greater exposure of surface in these bars than in hollow cylinders) as shown by the dotted lines, the diagonals in the direction of the ties a, a, a, have increased in length, while those in the direction of the counter-ties b, b, b, have shortened. But the counter-ties having themselves been lengthened by the heat, are consequently loose from a double cause, and the bridge is, while in this condition, entirely without a distributing system, and upon the engine coming on one end of the bridge, the other must inevitably rise until the counter-ties are tight, thus producing a vibratory wave in the truss, which is destructive to its permanency, and which is observable in the undulatory movement of this truss on a hot day. Where the deflection is caused by a load, this defect is still more marked, as in that case the upper chord and posts contract instead of expanding, while the main-ties and lower chord lengthen as before, thus rendering the counter-ties more incapable of performing their proper duty than in the former case.

THE BOLLMAN TRUSS.

In this truss, the effects of temperature are partially provided for by a suspension link at the foot of each post, and in short spans this arrangement answers the purpose, as the angle produced by the great proportional expansion of the long bar as the posts approach the abutment, is not sufficiently large to materially affect the adjustment of the truss. The posts, however, their feet being fixed by the floor stretchers or bottom chord, (this system of floor or chord stretchers between the feet of the posts and the abutments is used on all Bollman bridges both above and below grade,) must move in vertical lines and this throws the panel rods out of adjustment in the same manner as the counter-ties of the Murphy, when that truss is deflected from the effect of temperature. If, as is not unlikely to be the case, the stretcher bracing is not wedged tightly, a considerable portion of the strain arising from the load must, in this event, inevitably be thrown upon the panel rod, a result contrary at once to the main principle of the truss, demanding an increase of strength in this rod to meet this contingency, and showing the inapplicability of this truss to long spans, as this difficulty as well as the mechanical one, of the great concentration of tension bars at the end of the chord, increases in rapid proportion to the length of span.

From the above comparison, under the head of compensation, under strain and change of temperature, we may rank the several trusses thus—Fink, Triangular, Bollman (for short spans) and Murphy; under the head of adjustability or facility of restoration to their proper form, when deranged from any cause, we may place the trusses without much discussion in this order: Bollman, Fink, Triangular, Murphy, the difference between the two first being not great, and only more favorable to the Bollman truss, by reason of the panel rods of that system, which give a means of adjustment separate from that of the main tension bars, the panel rods being indeed an independent system of support, the want of harmony of action of which, with the main system of long and short tension bars, is one of the most striking imperfections of this truss under a load, but most useful in its adjustment.

The Triangular truss is manifestly more adjustable than the Murphy, owing to the superior simplicity of its elements and smaller number of parts, yet both these trusses from the dependence of their parts on each other, panel by panel, and to their want of such a thorough system of supports, and for transmission of strains to their abutments from intermediate points, as is possessed by the Fink and Bollman trusses, are deficient in their power of restoration to their normal condition after settlement without the aid of false works.

All of these trusses being in their several connections of parts under the control of screws and wedges are, so far as these arrangements are concerned, equally adjustable.

GENERAL CONCLUSIONS.

If the writer has in the preceding investigation applied sound principles to correct data, as he earnestly believes that he has, then the following results will have been established:

1st. That a single track railway bridge of 200 feet span and of the other dimensions and strength stated in the above estimate, of cast and wrought iron with wooden floor beams and railjoists, with the following amounts of material upon the four different models above discussed, would cost for material alone, at the scale of prices assumed for the purpose of this comparison, viz. For an overgrade or through bridge.

ON THE TRIANGULAR PLAN.

120,831 lbs. cast iron, @ 6 cts.	$ 7,249	86
73,809 lbs. wrought iron, @ 10 cts.	7,380	90
17,000 ft. B. M. lumber, @ \$45$\frac{00}{100}$	765	00
Total cost of material,	15,395	76
Cost per foot of bridge,	$ 76	98

MURPHY TRUSS.

143,363 lbs. cast iron, @ 6 cts.	$ 8,601	78
92,255 lbs. wrought iron, @ 10 cts.	9,225	50
17,000 ft. B. M. lumber, @ \$45$\frac{00}{100}$	765	00
Total cost of material,	$18,592	28
Cost per foot of bridge,	$ 92	96

FINK TRUSS.

126,744 lbs. cast iron, @ 6 cts.	$ 7,604 64
104,248 lbs. wrought iron, @ 10 cts.	10,424 80
17,000 ft. B. M. lumber, @ \$45$\frac{00}{100}$	765 00
Total cost of material,	$18,794 44
Cost per foot of bridge,	$ 93 97

BOLLMAN TRUSS.

128,524 lbs. cast iron, @ 6 cts.	$ 7,711 44
185,291 lbs. wrought iron, 10 cts.	18,529 10
17,000 ft. B. M. lumber, \$45$\frac{00}{100}$	765 00
Total cost of material,	$27,005 54
Cost per foot of bridge,	$ 135 02

MATERIALS AND COST OF THE FOUR TRUSSES, IF UNDER-GRADE BRIDGES.

MURPHY TRUSS—UNDER-GRADE.

Cast iron,	152,677 lbs.
Wrought iron,	93,459 "
Lumber, (17,000 ft.)	50,000 "
Weight of truss.	296,136 lbs.
Deficiency of strength after deducting for pier towers,	1,536 lbs.

BOLLMAN TRUSS.

Cast iron,	134,285 lbs.
Wrought iron,	186,908 "
Lumber, (17,000 ft.)	50,000 "
Weight of truss,	371,193 lbs.
Deficiency of strength after deduction for pier bed plates,	95,993 lbs.

FINK TRUSS.

Cast iron,	113,171 lbs.
Wrought iron,	98,778 "
Lumber, (17,000 ft.)	50,000 "
Weight of truss,	261,949 lbs.
Surplus strength after accounting for pier bed plates,	13,251 lbs.

TRIANGULAR TRUSS, UNDER-GRADE.

Cast iron,	144,846 lbs.
Wrought iron,	70,558 "
Lumber (17,000 ft.)	50,000 "
Weight of truss,	265,404 lbs.
Surplus strength after accounting for pier towers and tressels,	16,796 lbs.

In the above statements the Murphy is estimated as retaining the cast iron pier tower, which saves it twenty-one feet of masonry, the Beam trusses being usually built in this way, while in the Fink and Bollman the pier wall is considered as carried up to the upper chord, a mode of construction which, if it increases the first cost somewhat, also increases the stability. The Triangular also saves the twenty-one feet of masonry, but two iron tressels for carrying the roadway from the termination of the top chord to the pier or abutment are added to its cost. This twenty-one feet of masonry will be considered, therefore, in the estimates for the Fink and Bollman trusses—the iron pier towers of the Murphy and the tressels of the Triangular are included in the items of cast and wrought iron in these trusses.

MURPHY TRUSS, UNDER-GRADE BRIDGE.

ESTIMATE OF COST.

Cast iron, 152,677 lbs. @ 6 cents,	$9,160 62
Wrought iron, 93,495 lbs. @ 10 cts.	9,349 50
Lumber, (17,000 ft.) @ $45 00	765 00
Total cost per span,	$19,275 12
Total cost per lineal foot,	$ 96 37

TRIANGULAR TRUSS, UNDER-GRADE.

ESTIMATE OF COST.

Cast iron, 144,846 lbs. @ 6 cts.	$8,690 76
Wrought iron, 70,558 lbs. 10 cts.	7,055 80
Lumber, 17,000 ft. $45,	765 00
Cost per span,	$16,511 56
Cost per foot lineal,	$ 82 55

BOLLMAN TRUSS.

ESTIMATE OF COST.

Cast iron, 134,285 @ 6 cts.	$ 8,057 10
Wrought iron, 186,908 @ 10 cts.	18,690 80
Lumber, 17,000 @ $45	765 00
124 yds. of masonry, @ $12	1,488 00
Cost per span,	$ 29,000 90
Cost per foot lineal,	$ 145 00

FINK TRUSS—UNDER-GRADE BRIDGE.

ESTIMATE OF COST.

Cast iron, 113,171 lbs. @ 6 cts.	$ 6,790 26
Wrought iron, 98,778 lbs. 10 cts	9,877 80
Lumber, 17,000 ft. @ $45	765 00
124 yards masonry, @ $12	1,488 00
Cost per span,	$18,921 06
Cost per foot lineal,	$ 94 60

The same scale of prices has been assumed for all of the plans, as it cannot materially differ for any of them, the same quality of materials being required for all, and the work of putting them into shape and fitting together being about alike.

The advantage of first cost then for an overgrade bridge, is with the *Triangular*, the *Murphy*, the *Fink* and the *Bollman*, in this order and at the following prices per foot run, viz. Triangular $78 02—Murphy $92 95—Fink 93 97 and Bollman $135 02—For an undergrade bridge they stand—Triangular $82 55—Fink $94 60—Murphy $96 37 and Bollman $145 00.

Now as the relative merits of any number of forms of bridge truss, if they are assumed to be equally strong, safe and durable, must be determined by their comparative *first cost*, then we have the means of deciding under this one head which of the trusses here considered is most worthy of general adoption in their respective aspects, in an overgrade or undergrade position.

There are however, it must be admitted, other considerations besides first cost which have a legitimate bearing on the judgment of the engineer, who is selecting a plan for his bridge. These considerations which have been treated of in this paper, under the heads of "Compensation" and "Adjustments," deserve a further brief notice before bringing it to a close, as they show that the principles of the four trusses discussed, differ so much in these respects as to make it impossible to regard them as all "equally strong, safe and durable," but, that the question of "first cost" must be compounded with other points of merit and demerit under the heads just named.

Thus it is clear, that the truss which accommodates itself best to passing loads and temperature, must require less supervision and attention to its condition, and is kept in order at the least cost, and hence, if it be at the same time the cheapest to build, is also the cheapest to maintain, and so doubly the most economical and therefore the preferable. By combining this consideration with that of original cost, a still more satisfactory consideration can be reached from the premises afforded by the results of the preceding estimates.

Farther, these estimates if correct, show that the trusses as computed are not in fact equally strong, although it was the wish of the writer to bring them as nearly as possible to the same standard in that respect, but as he had to assume a certain weight for the truss, which happened to prove heavier or lighter, according to the truss under consideration, than was required by the load to be carried, the only way to show the relative strength of the different trusses, was to compare their calculated weights with the weight assumed, and see how far they fell short of or exceeded the latter. From this comparison it appears that the assumed weight of truss in each case being 272,000 lbs., and the estimated weights of the material borne by the truss, computed from the strains, being 242,440 lbs. in the Triangular, 263,018 lbs. in the Murphy, 258,392 lbs. in the Fink, and 341,215 in the Bollman truss, the three first showed a surplus strength of 29,560 lbs.—8,982 lbs. and 13,608 lbs. respectively, and the last a deficiency of 69,215 lbs. By this scale of strength the Bollman truss would break down with 98,775 lbs. less than the Triangular, 78,197 lbs. less than the Murphy, and 82,823 lbs. less than the Fink truss, all being overgrade bridges, and with 112,789 lbs. less than the Triangular; 109,244 lbs. less than the Fink, and with 94,457 lbs. less than the Murphy, all being undergrade bridges.

As the standard load upon the bridge was taken at 448,000 lbs., and the parts were proportioned to meet this strain, on the presumption that the truss itself would weigh just 272,000 lbs., consequently the variation above or below this assumed weight of truss, is just so much added to or subtracted from its load bearing capacity.

Therefore we have in an overgrade bridge,

TRIANGULAR.	FINK.	MURPHY.	BOLLMAN.
448,000 lbs.	448,000 lbs.	448,000 lbs.	448,000 lbs.
+29,560 "	+13,608 "	+8,952 "	—69,215 "
477,560 lbs.	461,608 lbs.	456,952 lbs.	378,785 lbs.

as the relative available strength of each, and in an undergrade bridge,

TRIANGULAR.	FINK.	MURPHY.	BOLLMAN.
448,000	448,000	448,000	448,000
+16,796	+13,251	—1,536	—95,993
464,796 lbs.	461,251 lbs.	446,464 lbs.	352,007 lbs.

are the measures of their respective efficiency.

It is plain, therefore, that to bring the four trusses to an equality of strength, the amounts of material in the Triangular, Murphy and Fink trusses, would have to be decreased, and that of the Bollman to be increased in the proportion in each of the weight of truss to its load bearing capacity.

The reason for this excess of material in the Bollman bridge, unaccompanied by any increase of strength, but on the contrary, a source of weakness by overloading with dead weight, are 1st, that this peculiar system of an independent support for each post, reaching to each abutment, involves the necessity of making that support sufficient to sustain not only the average load of one ton per foot over the whole truss, when covered by a train, but the much greater load of 84,000 lbs. on 12½ feet brought by the locomotive successively on every panel. Now this local load is sustained in the other trusses by short rods or bars reaching only through one panel, while in the Bollman truss they reach through the whole length of the truss. Hence, a single locomotive passing over, without a train, will strain every set of tension bars in the truss which form not only the local, but the general system of the truss to its extreme stress, while in the other trusses an engine alone will bring upon the general supports, but a small part of their extreme stress, and only that extreme stress on its local supports.

The effect of this anomalous feature of the Bollman truss, must be manifestly a vast increase of material, with no corresponding increase in general supporting power, and a most uneconomical arrangement of parts.

The panel or local diagonals which would not appear to be necessary to the principle of the Bollman truss, except to prevent a rising of the chord from partial loads, are doubtless introduced in order to effect a distribution of this local weight among several sets of tension bars, and if it were possible to make these two incompatible systems work together, some relief to the bars would be obtained, but as they must be adjusted at some one state of a temperature which is perpetually changing, it is evident that at any other temperature they must cease to act in harmony, in consequence of their greatly different length and sectional area. An expansion of the tension bars, the 20th part of an inch more than the panel rods would throw a large share of the strain from the former upon the latter, and a similar contraction would transfer it from the latter to the former, the compensation link notwithstanding, for the moment the link swerves from the vertical line one or other of the sytems becomes relatively inactive.

This subjection of both the local and general supports to a constant recurrence of the extreme strains, makes it necessary to allow the largest margin in the strains per square inch and requires as in the case of the panel systems of the other trusses, that 10,000 lbs. per square inch should be used as the working strain of the wrought iron, where it is habitually exposed to its full calculated capacity. In the distributing trusses this is the case with only about one-fourth of their tensile material, while in the Bollman it covers nearly the whole.

The strength of a bridge however, is the strength of its weakest point at its weakest moment, and this provision for particular strength at a series of detached points, *adds none whatever to the general strength of the structure: as the rest of the parts being graduated to bear the regular load over the whole length, its ultimate capacity amounts to this and nothing more*, while the weight of surplus material in the bridge itself, has of course to be deducted from its load bearing capacity.

The Bollman truss is advocated by some, on account of the supposed superior safety due to its independent support to each post; the idea being that if any one pair of tension rods gives way, all the others will hold, and so the truss be saved from wreck. This is however a mistake.

The Bollman truss would be as effectually broken up by the failure of one post, if a load was on the bridge, as the Triangular, Murphy or Fink by a similar failure ; for the upper chord which is common to all, would most probably be fractured and so the entire system would be destroyed. The panel rods in the Bollman truss, which look like auxiliaries, ready to render their aid in case of a fracture of the main tension rods, are manifestly too weak to supply the place of the latter in case of their breakage. The promised safety is but apparent, not real. The Bollman as well as all other trusses, depends on good material and workmanship. If the excess of material in this truss were put into any of the others, they would be stronger than it, because better arranged and the parts working in harmony with each other, instead of forming separate systems independent and incompatible. An unfavorable feature of the Bollman truss, growing out of the independent support of each post, is that the depression of the first post from the end, under an advancing train is nearly as great as that of the centre post, while in the other trusses the deflection gradually increases from the ends to the middle.

The increased shock to a train from this sudden sinking of the bridge in passing from its masonry supports, must be manifestly hurtful to both train and bridge.

It may be objected that the proportions of some of the trusses here examined differ from those used by their patentees or builders. If they do, then if the estimates of this paper are correct, they are either too light or unnecessarily heavy : and as the estimates are open to invited criticism, it is awaited with the mind of the writer open to conviction. It is probable that all of the trusses as here proportioned, are somewhat heavier than they are usually built, as the writer has generally found very little attention paid by most bridge builders to the important facts, that the great weight of the modern engines more than doubles the old standard working strains on the panel systems of the Suspension trusses, and this, together with the consideration of the effects of partial loads on the Beam trusses, (as explained in this paper,) must necessarily cause an increase in the proportions of the latter.

The calculated material in the Fink Truss, however, is less by several thousand lbs. of cast iron than in the Barren river bridge taken as the standard in the early part of this paper. This is owing to the shortening of the posts in the sub-systems of the truss here estimated for. A corresponding increase in the wrought iron is due to the same cause, so it is evident that the Barren river bridge is fully up to the standard strength. It is due to the inventor of this truss to state that the long post principle, as used in the Barren river bridge, is preferred by him over the short post system considered in the present article.

Before closing this paper the writer deems it essential to farther explain his views relative to the matter of compensation. In the review of the Murphy Truss the inefficient system of counterbracing and consequent want of rigidity in the truss is condemned as a serious defect in the principle of the bridge; why then is the Triangular Truss not equally faulty in this particular, since the distributive principle is nearly the same in both? In the latter, however, we have the power of applying a mechanical corrective to the difficulty which in the former cannot be done. This simply consists in passing the counter-tie connecting top and bottom chords through the interior of the cast iron inclined brace and thus sheltering it from thermal effects except as received through the cast iron column. By loading the bridge from end to end with the heaviest train which can be brought upon it and screwing down the counter-ties while it is in this condition, an equilibrium of adjustment will be established which will not again be disturbed. This matter of shielding a small but important rod from the direct effects of the sun or cold is of much more importance than it is usually considered. A bar of small section will frequently be heated through, and expanded to its full extent before the larger parts have absorbed heat enough to have perceptibly changed their length. The writer has been delayed for an hour or more during the erection of a bridge from the fact that the bridge was in the sun and the pile of tension bars that were being used in the shade. Where several bars went on the same pins and some of these were already fitted, the bar brought from the pile on the bank was frequently too short and could not be got on the pins until it had lain in the sun long enough to be heated to the same temperature as those already on. It is this fact that renders the support system of the Bollman and the distributive system of the Murphy so liable to derangement. In the first, the long tension rod of each system will have expanded to its full extent before the chord has fairly begun to move, or have contracted in like manner; and in the second, the counter-ties will be loose some hours before the expansion of the posts is sufficient to take up the slack. This difficulty can be partially obviated, in the Murphy Truss, by heavily loading the bridge and adjusting the counter-ties on a hot day, but in a long span there is danger in this case to the counter-tie, in winter, of the contraction straining it to an unsafe degree. In the similar and equal sided triangles with changeable angles of the Fink, there is of course no difficulty of this kind whatever, while in the equiangular and equilateral systems of the Triangular the action of the supporting system is almost as perfect, and the distributive system thoroughly protected.

There is yet another point to be considered, viz. adaptability to every length and character of span and proportion of truss. In this the question is first between the Beam and Suspension trusses, and afterwards between the individuals of each class. The facility with which the undergrade Suspension trusses can be narrowed, and their peculiar fitness for short spans and shallow trusses, render their use very often advisable in cases where, if a Beam truss were adopted, an overgrade bridge would become necessary at a considerable increase in the cost of both bridge and masonry. An undergrade Fink of 60 feet span, 6 feet depth of truss and 6 feet width between chords, is by no means an uncommon structure, but to build a Beam truss of these proportions requires such an increased number of panels and joints that its cost is greater than that of the other, while its action under a load is much inferior. Such a bridge as the Fink, just described, requires very little masonry and can frequently be used in places where, otherwise, an overgrade bridge would become necessary, with of course, masonry piers at least 20 feet long, and a truss not less than 17 feet high. This class of truss, when the bridge is undergrade, is advisable in nearly all cases, as, notwithstanding the fact that in the foregoing estimates the cost of 21 feet of masonry has been added to the cost of this truss for sake of comparison, the difference in the necessary cross sections of the masonry will, in a majority of instances, more than make up for the added height, and frequently for the difference in cost between the trusses. Under these circumstances, therefore, the Fink, as the best and cheapest of its class, is the preferable bridge to use, and where, as in the assumed case, the cost of the Fink with its masonry is the same or nearly so with that of the Triangular and its masonry, the former being as we have seen the superior truss of the two, so far as perfection of principle and action are concerned, is clearly the bridge to be adopted.

Where, however, an overgrade bridge has necessarily to be used, and the spans are less than 100 feet, other considerations present themselves. All beam trusses possess this defect, viz. that in them the main lines of strain, either compressive or tensile, must turn an angle at some point between their two extremities: with the bridge either fully loaded or without any load at all, the strains on either side of this angle are equal and the truss is in equipoise, but with a partial load on the bridge this equilibrium is at once destroyed and the dynamic effort to straighten the angular lines of strain produces a tendency to change of shape in the truss which must be resisted by a thorough system of counter-ties or bracing. In short spans, where the weight of the truss is light in comparison with that of the train, this constant action and reaction of the strains is very injurious to the permanency and safety of the truss, so much so, in fact, as to render this class of structure by no means an advisable one under these circumstances. As the comparative weight of the truss to that of the load increases with the span, and the proportional dynamic effect is, therefore less, and the bridge more stable, consequently in long spans this objection is no longer valid. For short span overgrade bridges, therefore, the Suspension trusses are clearly the preferable, as in them there are no angular lines of strain and consequently no tendency to change of shape whether the weight of the load be great or small in comparison with that of the truss. For this style of bridge then, the contest lies between the Fink and the Bollman, and although in a long span the superiority of the former is manifest, yet in the present case the difference is not so apparent. The Bollman owes its great comparative first cost in a long span principally to its system of independent panel supports and want of a distributive system. In spans of from 60 to 100 feet, however, the small number of panels necessary, makes but a limited distribution possible, and the consequence is, that in these cases where the engine will cover from the half to the whole of the bridge the gain of the Fink over the Bollman is not great in this respect, while the Bollman possesses a decided advantage in the non-transmission of strains to the tops of its posts, thus rendering the amount of cast iron required less than in the case of its competitor. Its inferiority in the matter of compensation is not felt in these short spans, as the lengths of the parts are not sufficient to render their inequality of expansion at all serious as a disturbing element, and it has besides an additional advantage in the fact that no irregular number of panels can effect its gradations of cost per foot lineal, while in the Fink, when an odd number of panels becomes necessary, it is always attended with a certain loss in economy of material. To illustrate,—in a 45 feet span, overgrade, the Fink requires four panels and three posts, or else an unsymmetrical arrangement of two posts, which costs nearly as much as the three, while the Bollman will have but three panels and two posts, and will contain the least material of the two. At 60 feet span the Fink is again ahead but is irregular from 70 to 90 feet, at which last point it takes the lead and gains steadily afterwards with every increase of span. For short overgrade spans, therefore, the Fink and Bollman are about equal in their respective advantages, and both are decidedly superior to the Beam trusses.

From what has already been said concerning the tendency of the latter trusses to change their shape with a partial load, it is manifest that if, in the case of overgrade bridges of considerable span, the Suspension trusses are no greater in cost and equal in point of compensation and strength to the Beam trusses, they are still the best of the two classes of bridge. We find, however, that between the Murphy and Bollman the former has the advantage in both these considerations; the latter then being ruled out the Fink and Murphy next come into competition. Here the cost is nearly equal, with all the advantages of perfection of principle and economy of material and weight on the side of the Fink. This narrows the contest down to the Fink and Triangular, each the best representative of its class. The Fink is superior in its principle, its adjustability, and its compensation. The Triangular, where the spans are over 100 feet, is nearly equal in respect to the first and last of these and is ahead in the considerations of first cost and economical distribution of material. It is in this case then evidently the proper truss to be used.

Taking, therefore, all the points above reviewed into consideration, the conclusions would seem to be these, viz. that for all spans where the weight of the train is great in proportion to the weight of the truss, the Suspension trusses (there being in them no tendency to change of shape) are the best, and of these two the Fink is almost invariably preferable. This truss also ranks first for an undergrade bridge of any length of span, while for all overgrade bridges of more than 100 feet span the Triangular is the best truss. In perfection of principle, of action under a load, of general adaptability, and of compensation for the disturbing influences of temperature, the Fink stands first; in point of economical distribution of material, of proportional strength to weight of truss, and in first cost, the Triangular has the lead; while in the matter of adjustability the Bollman is superior to its competitors and is equal to the Fink under certain circumstances as a short span overgrade bridge.

Such then are the relative positions of the Fink, Triangular, Murphy and Bollman trusses; all good bridges; all when properly proportioned and faithfully constructed, equal to any of the requirements of a railroad bridge, but having, as has been shown, various degrees of excellence. It is needless to say, that equally good material and workmanship is assumed in all cases, and that the best form of truss badly constructed may break down sooner than the worst, if the last is well built.

Before concluding, the writer would remark, that among American bridges there are, in addition to the trusses above reviewed, several other Beam trusses which are well worthy of attention. Of these, the bridges of Messrs. Whipple, Laurie, Post and Linville, have been especially successful, the last named gentleman, particularly, having constructed some large bridges which are not only a credit to himself but an honor to his country.

A synopsis of the results of these investigations is appended, and in closing this paper the writer would say that while he expects that his views may be disputed by professional men, on theoretical grounds, and will probably be assailed by others whose interest in the subject is of a less abstract character, he trusts that any discussion which may ensue may be conducted in a manner and spirit that may lead to results of general utility.

His object is to promote bridge building on the best plan, and if he has not as yet discovered that, he desires to be directed into the path which will lead to it, that he may obtain a share of the work which is to be done in the wide field which is now open in this important department of construction.

SYNOPSIS OF RESULTS,

Arrived at from a Comparative Analysis of the Strains in the Fink, Bollman, Murphy and Triangular Trusses, and an assignment to each of the exact amount of material in each part necessary to resist the same, according to the conditions of the case, viz. that each truss shall be able to sustain a load of one ton per foot over the whole of its length, and a concentration of 84,000 *lbs. on any panel of its length, without straining any part to more than one-fifth of its breaking weight.*

OVERGRADE BRIDGE.

Name of Truss.	Weight of Material in each Truss.	Weight of Pier Tower, &c., not borne by the Truss.	Actual Weight of material borne by Truss.	Weight of Truss assumed for calculation.	Surplus Strength.	Deficit in Strength.	Weight of Load assumed in the calculation.	Load Bearing Capacity of Truss as proportioned.	Coefficient, expressing relation of wt. to load bearing capacity.	Relative order as to Compensation.	Relative order as to Adjustability.	Relative order as to adaptability to all Spans & Positions.	Relative order as to first cost.	REMARKS.
Fink..........	280,992	22,600	**258,392**	272,000	13,608		448,000	461,608	1.78	1	2	1	3	The compensation of the Bollman is superior to that of the Murphy for short spans.
Triangular .	244,640	2,200	242,440	272,000	29,560		448,000	477,560	1.97	2	3	2	1	
Murphy......	285,618	22,600	263,018	272,000	8,982		448,000	456,952	1.73	3	4	3	2	
Bollman.....	363,815	22,600	341,215	272,000		69,215	448,000	378,785	1.11	4	1	4	4	

UNDERGRADE BRIDGE.

Name of Truss.	Weight of Material in each Truss.	Weight of Pier Tower, &c., not borne by the Truss.	Actual Weight of material borne by Truss.	Weight of Truss assumed for calculation.	Surplus Strength.	Deficit in Strength.	Weight of Load assumed in the calculation.	Load Bearing Capacity of Truss as proportioned.	Coefficient, expressing relation of wt. to load bearing capacity.	Relative order as to Compensation.	Relative order as to Adjustability.	Relative order as to adaptability to all Spans & Positions.	Relative order as to first cost.	REMARKS.
Fink..........	261,949	3,200	258,749	272,000	13,251		448,000	461,251	1.78	1	2	1	2	
Triangular .	265,404	10,200	255,204	272,000	16,796		448,000	464,796	1.82	2	3	2	1	
Murphy......	296,136	22,600	273,536	272,000		1,536	448,000	446,464	1.63	3	4	3	3	
Bollman.....	371,193	3,200	367,993	272,000		95,993	448,000	352,007	0.96	4	1	4	4	

NOTE.—The weight of pier tower used in the foregoing estimate and made common to all the trusses except the Triangular, is that of a set of Towers now in use under a bridge of this span and depth of truss. By using the single pillar, movable on its pedestal for the Murphy, instead of the fixed tower, a saving could be made for that bridge of several thousand lbs. of cast iron, but the arrangement is not equally stable and safe.

The writer of the foregoing is gratified to be able to add the following brief review by Benj. H. Latrobe, *Civil Engineer.*

Baltimore, *Nov'r 29th,* 1865.

The memoir by Mr. C. Shaler Smith, upon the comparative merit of different forms of bridge truss, has been submitted to me by that gentleman for my professional opinion, and after an attentive examination of his paper I am prepared to say that I consider the principles upon which he has conducted his investigations to be scientifically accurate, and his conclusions correct. The declared purpose of his publication being, as he states, to exhibit in a practical way the several advantages and defects of the four patterns of truss now principally competing for public favor, his object is undoubtedly a useful one and he has employed the proper means to accomplish it. He does not make himself the champion of any one model but fairly sets forth the properties of each, inviting criticism from those whose views may differ from his own. He does not disparage any one of those treated of, but temperately points out what he regards as its deficiencies, admitting that bridges can be made, strong and safe, even upon the plan he considers most open to objection, and bringing their respective claims to adoption to the test of *economy* in construction and maintenance. This is, unquestionably, the true mode of comparing them, and the only real standard of excellence—the question being this—given the strength, stiffness, safety and durability required, by what form of truss can this be attained, in an assumed case, *at the least cost?* Treating the subject as he has in this manner, I must agree in his conclusions, and hope that his treatise may be the means of leading to beneficial results in railway economy. That bridges have been built, are being built and will hereafter be built, of all the forms treated of and many others, and that they *have* stood well and *will* stand well hereafter is surely true—but the question still remains open: whether they could not have been made or can be made to stand, *equally well,* with a less investment of capital, and consequently better dividends to railway companies, or cheaper transportation to the public.

I express the preceding opinions without bias from pecuniary interest in any existing form of bridge.

BENJ. H. LATROBE,
Consulting Engineer.

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